Compliments of L. Lewton-Brain

A. D. Cotton

DIVISION OF PATHOLOGY AND PHYSIOLOGY. BULLETIN No. 7

REPORT OF WORK

OF THE

EXPERIMENT STATION

OF THE

HAWAIIAN SUGAR PLANTERS' ASSOCIATION

IMPERIAL BUREAU OF MYCOLOGY
28 JUN 1921

A LECTURE ON

Rind Disease

OF THE

Sugar-Cane

WITH 16 ILLUSTRATIONS

BY L. LEWTON-BRAIN

HONOLULU, H. T.

1907

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LETTER OF TRANSMITTAL.

To the Experiment Station Committee of the
Hawaiian Sugar Planters' Association:

Honolulu, T. H.

Dear Sirs:

I, herewith, submit for publication as Bulletin No. 7 of the Division of Pathology and Physiology, an article entitled "Rind Disease of the Sugar-Cane." This article has been prepared by Mr. L. Lewton-Brain, Assistant Director of this Division.

Yours very respectfully,

N. A. Cobb,
Director, Division of Pathology & Physiology.

Honolulu, T. H., March 12th, 1907.

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Rind Disease of the Sugar-Cane

By L. LEWTON-BRAIN.

AN ADDRESS ON RIND DISEASE AND OTHER RELATED STEM DISEASES OF SUGAR-CANE, DELIVERED BEFORE THE HAWAIIAN SUGAR PLANTERS' ASSOCIATION; HONOLULU, 1906.

Among the numerous diseases of cane present in these islands, caused by parasitic fungi, there are three that stand out as the most important by reason of the obviousness of their effects and of the amount of loss they produce. These three are

1. Root disease,
2. Rind disease of the stem,
3. Pine-apple disease of cuttings.

Other diseases cause considerable damage, but either the damage is not so great as it is in the three I have mentioned, or the disease itself is more obscure. In the latter case, although the loss may be large, the cause of it is not easily recognizable and the importance of the disease is not realized.

At the last Annual Planters' Meeting I laid before you the facts, so far as they were then known, with regard to root disease.* A bulletin was also issued dealing with the same subject and suggesting the lines on which the disease could be fought. I may add that our knowledge of the cause of root disease has since been considerably extended by Dr. Cobb's observations on Hawaii. Also we have come to a clearer knowledge as to the values of the different lines of treatment; the importance of cultivation and of the destruction of diseased material, in this connection, has become more and more apparent.

It has been suggested that this year I should deal in a similar way with what is now, perhaps, the next most important cane

* Since this address was delivered, it is interesting to note that the opinion I expressed, in my lecture on Root Disease, that the root disease of Java and the West Indies would prove to be present in Hawaii has been confirmed by the discovery, in a number of localities on different islands, of the fructifications of *Marasmius sacchari*.

disease, that generally known as the rind disease. I shall try to put before you the present state of our knowledge of rind disease and the fungus which is the immediate cause of it, suggest remedies, or, rather, methods of preventing the disease from attacking our cane, and also to indicate the points at which our knowledge is incomplete, and the lines our investigations must follow to clear up these points.

STRUCTURE OF CANE STEM.

Last year before describing root disease and its effects on the cane plant, I discussed briefly the structure of the root system of the cane and the functions of its parts. I propose now to treat of the stem of the cane in the same way and for the same reasons. We cannot, without knowing the normal structure of an organ, understand the derangements set up in that organ by the attack of parasites. Without knowing something of the functions of the parts of any system, we cannot understand how a derangement of one part will affect the working of the whole. The study of anatomy and physiology is a necessary preliminary to the study of pathology. There are a few parasitic fungi which are purely local in their effects; but the majority of them, though, perhaps attacking only one organ, by so doing throw the whole system of the plant out of order, and so affect the health and possibly the life of every part of the plant.

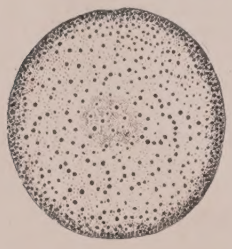


FIG. 1. Section through the upper portion of a cane stalk, natural size, as seen against the sky. The vascular bundles are seen as dark spots in the clear ground tissue; it will be noticed that they are more numerous towards the outside. One of the main functions of the bundles is to strengthen the stem mechanically, this arrangement gives the greatest mechanical efficiency with the least expenditure of material.

On cutting across a stick of cane, one notices first that it consists of two, more or less distinct, parts. On the outside is the harder woody part we usually call the rind; while inside this is a softer, more juicy part. There is no sharp line of distinction between bark and wood as in the cases of ordinary dicotyledonous plants, but the two regions merge, more or less gradually according to the variety of cane we are dealing with, into one another.

If now we examine such a cross section with a good pocket lens—a thing that every one who has dealing with plants should possess—we see scattered irregularly through what may be called a general ground mass of soft tissue a number of stouter strands or fibres. These strands, as you will see on splitting a cane longitudinally, run straight down the internodes. At the nodes

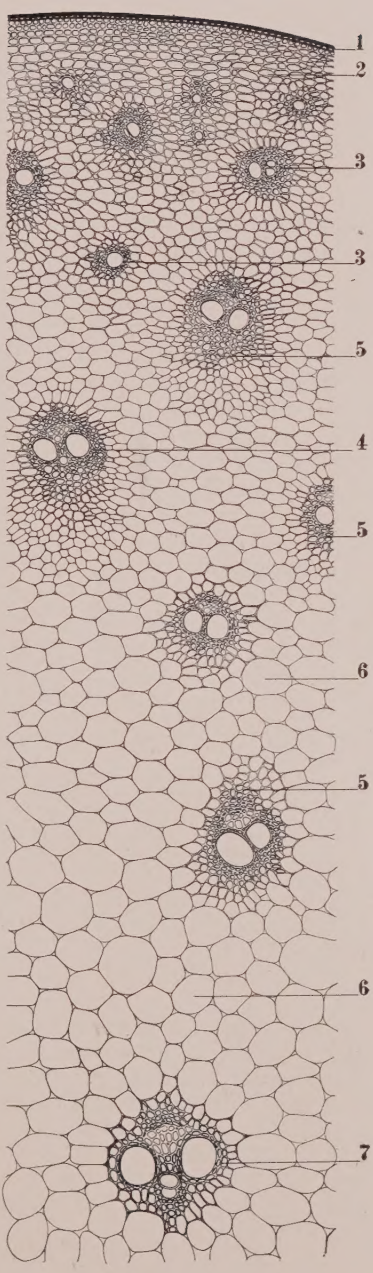


FIG. 2. Section through the outer part of a cane stem, as seen under the low power of a microscope. 1. The epidermis; notice the thick cuticularized walls, especially the outer ones; these walls are very tough and are impervious to water, thus the epidermis protects the more delicate tissues inside. 2. Thick-walled ground tissue of the "rind," these cells are mainly mechanical and help to strengthen the stem. They pass gradually into the thin-walled cells of the ground tissue, which are seen at 6. 3. 3. Small vascular bundles; these bundles are mainly mechanical and are composed almost entirely of thick-walled elements. They are found mainly in the outer part of the stem; each contains only one wood vessel. 4. Intermediate bundle, with two wood vessels, and a few thin-walled phloem elements. 5. 5. 5. Thick-walled fibres; these are the mechanical elements of the bundles, they are proportionately much more numerous in the bundles towards the outside, than in those nearer the centre. 6. 6. Thin-walled cells of the ground tissue, they become larger as we approach the centre of the stalk. Some of these cells are shown in more detail in Fig. 3. In these cells the plant stores its reserve of sugar and other food materials. 7. One of the large vascular bundles found towards the centre of the stalk, these are the chief conducting bundles; each contains lwo large wood vessels and one smaller, and a well-marked phloem.

(joints) they become interwoven in a complicated manner; here, some of them pass off into the buds and into the leaves, where they form the veins. When roots are formed their strands also become connected up to those of the stem.

To get a more detailed knowledge of stem structure, we must cut a thin slice transverse to the stick and examine it under a microscope, first with a low magnification. Starting at the outside, we find a single line of tabular cells, the *epidermis*. These epidermal cells have their outer walls considerably thickened, and

these walls are also chemically changed by the formation in them of a substance called cutin, while outside this is sometimes deposited a layer of wax. Cutin has very distinctive properties, the most important being that it is very impervious to water; in this way its presence in the walls of the epidermal cells prevents the tissues inside from losing water by evaporation and consequent drying up; it also prevents water from the outside soaking in to the tissues; in this it is assisted by the waxy incrustation. Another very important property of cutin is that it is extremely resistant to the attacks of fungi; very few parasitic fungi can penetrate an uninjured cuticularized membrane. The importance of the epidermis and of keeping it intact will thus be easily realized, especially when we remember that the cane has no power of replacing it by a cork layer, so that once a wound is made it can never be closed up.

The young epidermis is not cuticularized, its walls are composed simply of cellulose, which is quite pervious to water. This is why a young stem or leaf, when exposed to drying conditions, dries or wilts much sooner than when mature. The cellulose wall offers also much less resistance to fungus attacks, and to insect punctures. In the cane stem, the young immature part is protected from drying and from injury by the leaf sheaths which wrap round it and, naturally, only fall off when the epidermis has taken on its mature condition.

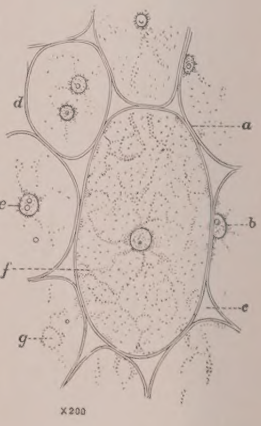


FIG. 3. A few cells from the healthy tissues of seedling cane; a, cell wall; b, nucleus; c, intercellular space containing air; d, a cell with two nuclei; e, a nucleus containing two nucleoli; f, protoplasmic network.

It is cells similar to these that compose the elements of the thin-walled ground tissue of the stem. The protoplasm is the living matter, of which the nucleus is a specialized part. The interstices of the protoplasmic network are filled with a watery solution, the cell-sap, in solution in this are a number of substances, one of the most important being the sugar stored here by the plant as a reserve.

These are the cells attacked by the rind fungus, which kills them and robs them of the stored sugar, thus causing the dull, sunken appearance of diseased joints.

GROUND TISSUE.

The remainder of our section consists of ground tissue in which are scattered the vascular strands. Towards the outside the cells of the ground tissue tend to be smaller and to have thicker walls. For the most part, however, these cells have thin walls and have protoplasmic contents; it is in these that the reserve sugar is stored by the plant. Their protoplasmic network does not fill the

cell, but leaves spaces, the vacuoles, filled with a solution called the cell sap; the most important substance contained in solution is the cane sugar, which is stored there by the plant as a reserve for future needs.

Fibro-Vascular Strands.

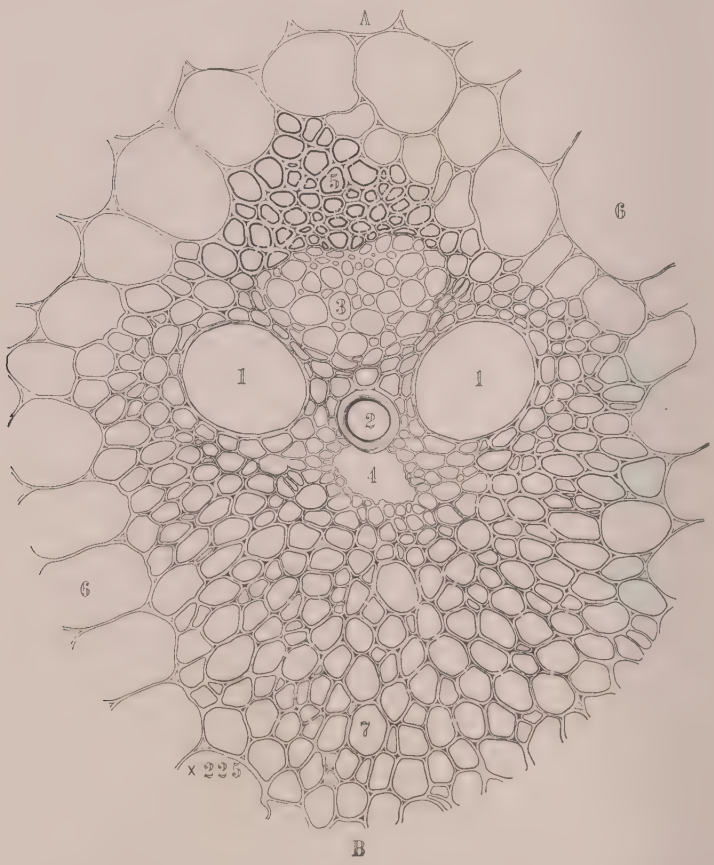
The vascular strands are more numerous towards the outside of the stem and there also they are noticeably smaller than those nearer the centre of the section. The most conspicuous features of the strands are the two or three large, thick-walled elements. These are the *wood vessels;* they are long pipes, which have been formed by the fusion of several shorter cells; they have lost their protoplasmic contents, while their walls have become woody and thickened in various ways. As I mentioned last year, the vessels connect above and below with other similar pipes, the terminations of the system being above in the leaves and below in the roots in the region of the root hairs.

On the outer side of the wood the strand contains a smaller group of thinner walled elements, the *phloem* or *bast.* The largest and most important of these elements are the so-called *sieve tubes;* these also are vessels, but instead of the dividing walls between the original cells quite breaking down they only partly do so. What remains of this wall is a plate with a number of holes in it, the sieve plate. The sieve tubes do not lose their protoplasmic contents, nor do their walls become woody.

Besides the wood and the bast the strand contains a number of very thick walled elements, the *fibres.* These are elongated dead cells with strong woody walls. Sometimes there is one group on the outer, and another on the inner, side of the strand; sometimes they form a thick mass surrounding the whole strand. It is noticeable that they are far more abundant with the small strands towards the outside of the stem, than with the inner larger bundles. Their function is purely mechanical and this concentration towards the outside is sound mechanically, on the same principle that a given amount of iron or steel in the form of a hollow cylinder is a stronger support than the same amount used as a solid rod—that is for the kind of strain a stem is subjected to—with a root the case is different. It is this difference in the relative amounts of mechanical tissue between the inner and outer parts of the stem that makes the difference between the rind and the remainder of the stem.

FIG. 4. Cross section of a fibro-vascular bundle of seedling cane. The bundle was taken from near the top of an eight months' old seedling, and was not yet fully lignified. The bundle has a similar structure to that shown at 7, in Fig. 2.

1, 1, the two large wood vessels with unbordered pits; 2, an annular vessel; 3, a sieve tube, a number of these thin-walled elements are shown; they, together with the smaller companion cells, make up the phloem or bast; 4, intercellular air space; 5 (and 7), thick-walled mechanical elements, the fibres, here forming a sheath around the bundle; 6, thin-walled cells of the ground tissue (parenchyma); 7, fibres; A, outer side of the bundle; B, inner side.



It is through the wood vessels that the upward current of water and dissolved food-salts travels from the roots to the leaves; any interference with this current, of course, puts a check on the manufacture of sugar, etc., which is taking place in the leaves. The sieve tubes convey the elaborated food, which has been worked up in the leaves, to the growing points and other parts where food is being consumed; a large part of the sugar is stored up in the thin-walled cells of the stem, shown at 6. The fibres are the supporting tissue of the stem; as shown in Fig. 2, these are proportionately much more conspicuous an element of the bundles of the outer part of the stem, than in these larger bundles which are found in the central part.

THE NUTRITION OF THE CANE IN SO FAR AS IT AFFECTS THE STEM.

Last year I pointed out how the root hairs, which are in close contact with the soil particles, take up this water with the mineral salts in solution, and pass it on by the process of osmosis, to the living cells of the root cortex. From these cells it passes into the wood vessels of the root.

Once in the wood the watery solution travels entirely in the cavities of the vessels. It passes up the whole length of the root, from one vessel to another, until finally it is passed on to the vessels of a connecting vascular bundle of the stem. In the stem the water follows the same path, always in the wood vessels, until finally the bundle passes out and becomes one of the veins of the leaf. Finally, in the leaf, the solution passes out of the vessels into the living cells of the leaf. These are the cells which contain the green colouring matter, known as chlorophyll, which is contained in certain specialized parts of the protoplasm, the chloroplasts. In these cells the mineral salts—nitrates, phosphates, potash salts, etc.,—are retained, as is also a part of the water. The excess water is transpired into the air spaces of the leaf and finally passes as water vapour into the air by way of the breathing pores or stomata.

The remainder of its food the plant gets from the air. The green cells of the leaf absorb the gas carbon dioxide from the air contained in the air spaces. Now a complicated series of reactions goes on of which we can only catch a glimpse here and there. This much is certain, however: the carbon dioxide and water are decomposed, oxygen gas is given off and cane sugar is produced. Possibly carbon monoxide is first formed and then formaldehyde; but this is to some extent theory, though supported by a number of experimental facts.

These processes require the expenditure of a considerable amount of energy, and this is where we see the importance of the chlorophyll. This green substance is able to seize on the energy of certain light rays—either from the sun or from artificial light—and, as it were, hand it over to the protoplasm in the form of chemical energy, which is used in converting such simple inorganic substances as carbon dioxide and water into a comparatively complex substance as cane sugar. The importance of this storage of energy in an available form by green plants cannot be overestimated, but I cannot enter into a discussion of that now.

The sugar formed in the leaves cannot remain there or the activity of the protoplasm would soon cease. It is probably changed

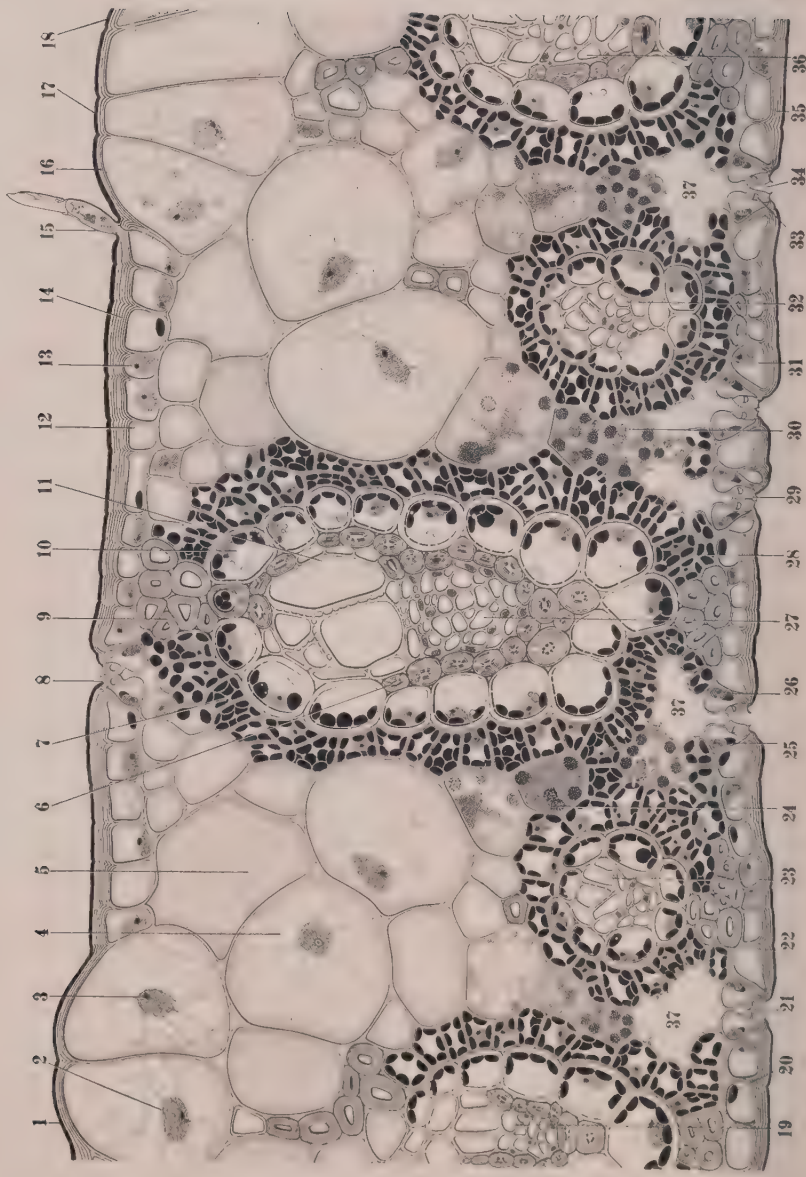

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Fig. 5. — Cross-section of a portion of cane leaf taken half way between the midrib and the margin near the middle of a full-grown but not yet fully lignified leaf. The upper side of the figure, 1 to 18, represents the top surface of the leaf. This figure, together with those preceding it, illustrate some of the complexities of the cane plant. Most of the illustrations are of course views as seen through the microscope. The part of the leaf to be examined was fixed with the vapor of osmic acid while still attached to the cane plant. The fixed portion was differentiated into glycerine and cut in that condition. The drawing was projected from a microphotograph and sketched. The details were drawn in from the examination of sections either unstained or stained with aniline safranin. The section shows five fibro-vascular bundles, the largest of which is indicated at 6 to 11 ,the smallest at 23 and 32. Portions of the other two, which are intermediate in size, are shown at 19 and 36 None of these bundles are of the largest size. Bundles fully twice the size of the larger here shown, and resembling that shown in Fig. 4, occur in the cane leaf, and such large bundles are characterized by the possession of annular vessels, none of which occur in these smaller bundles Throughout the illustration structures of the same class are indicated by a similarity in the draughtsmanship, thus the woody cells indicated at 9 are repeated in various parts of the figure, more particularly next to the epidermis of the lower surface

1, a set of so-called motor cells, in this instance composed of two cells, whose nuclei are pointed out at 2 and 3; 4, an internal cell of somewhat similar character to that pointed out at 1, 2 and 3; 5, another cell of the same class cut in such a way that the nucleus has been removed, 6, sclerenchymatous cells imparting strength to the fibro-vascular bundle; 7, one of the layer of parenchymatous cells rich in chloroplasts and immediately surrounding each fibro-vascular bundle; 8, one of the stomata, found more rarely on the upper than on the lower surface of the leaf; 9, woody cells imparting strength to the cane leaf, and occurring on the dorsal and ventral side of each fibro-vascular bundle. 10, one of the cells constituting the sheath of the vascular bundle, — these cells contain chloroplasts arranged along the outsides of their walls; 11, tracheal vessel; 12, one of the cells of the upper epidermis; 13, nucleus of a similar cell; 14, upper cuticle at its usual thickness; 15, a two-celled hair on the surface of the leaf; 16, thinner cuticle of the upper surface of the leaf as it occurs over the so-called motor cells; 17-18, group of so called motor cells, consisting in this case of four cells; 19, fibro-vascular bundle of intermediate size, 20, chloroplast in one of the cells of the lower epidermis; 21, one of the stomatic openings that are abundant on the lower surface of the leaf, this one is closed, — an open one may be seen at 25-26; 22, accessory (?) cell of the stomatic opening; 23, one of the smallest fibro-vascular bundles; 24, one of a group of cells very rich in protoplasm which extends between the vascular bundles. — the nearer these cells are to the lower epidermis the denser their protoplasmic contents, 25-26, protoplasts in the guard cells of the stomatic opening, 27, one of the sieve tubes, — among these sieve tubes may be seen the smaller companion cells and their protoplasts; 28, extra chlorophyll bearing cells outside the single layer surrounding the vascular bundle; 29, lip of one of the stomatic guard cells; 30, cell rich in protoplasm, of the same class as 24; 31, nucleus of one of the companion (?) guard cells; 32, fibro-vascular bundle of small size; 33, apparently a locule in the thickened portion of the wall of the stomatic guard cell, 34, entrance between the guard cells of the stomatic opening; 35, cuticle of the lower surface of the leaf; 36, fibro-vascular bundle of intermediate size; 37, 37, 37, air chambers immediately above the stomatic openings. Throughout the illustration the nuclei are shown gray and the nucleoli black.

first by certain ferments of the leaf into other sugars. Part of the product is used at once, part is stored ready for future use. That required at once is carried to the growing points of stems and roots or wherever it is required; the excess is carried to the thin-walled cells of the ground tissue of the stem and there stored as cane sugar.

The path these elaborated food materials take is also in the vascular bundles, not in the wood, but in the sieve tubes of the bast.

You will thus realize the great importance of the fibro-vascular bundles of the stem in the life of the plant. Not only does the raw food supply of water and mineral salts travel up the wood vessels from the roots to the leaves, but also the elaborated foods manufactured in the leaves are carried by the sieve tubes to all parts of the plant. Interference with either of these currents means at once a loss of food to all parts of the plant, resulting in bad health and, finally, if carried to excess, death.

Besides the formation of sugar, other, more complicated, changes go on in the leaf, also in sunlight. We know very little of the processes leading up to these changes, but from the sugar it has formed and the mineral salts brought up in solution from the roots, the leaf protoplasm builds up a series of nitrogenous compounds and produces finally the complex bodies known as proteids, and these are, somehow, built up into the substance of the living matter, protoplasm itself. The nitrogenous compounds, like the sugars, are conveyed from the leaf, to wherever they are wanted, by way of the sieve tubes.

FUNCTIONS OF THE STEM TISSUES.

Taking the various tissues of the stem in order, we see their functions are as follows: The epidermis first of all protects the watery inner tissues from the loss of water by evaporation; thus if one exposes plants grown in a glass house, or the young parts of a cane stem, whose epidermis is not well cuticularized, to the drying action of wind and sun they very soon wilt. By its toughness, the epidermis also helps to protect the tissues inside from wounds. Finally, the cuticularized epidermis is very resistant to the attacks of parasitic fungi; the ferments which these secrete, and which dissolve ordinary cellulose and even woody cell walls, are, speaking very generally, without effect on cutin.

The thick-walled woody cells immediately inside the epidermis function as mechanical tissue; their walls are hard and elastic and

are capable of withstanding great strain. These cells also help to protect the inner tissues from mechanical injuries such as the punctures of insects; in this way they also serve to help keep out fungus spores, which enter by these wounds.

The living thin-walled cells of the ground tissue, serve as store houses in which the cane puts away its surplus food material ready for future use—from the sugar planter's point of view, ready for his use.

The fibro-vascular bundles contain both mechanical supporting tissue, and conducting tissue. Those towards the outside, with their abundance of woody fibres, function mainly as supporting tissue. Those further towards the centre, with their larger vessels and smaller proportion of fibre, are mainly conducting. The thick-walled wood vessels serve to carry the water current from the roots up to the leaves. The sieve tubes carry the elaborated food—sugars, etc.—from the leaves down to where there is a demand for it, either for growth or respiration or to be stored away.

RIND DISEASE.

Most people in Hawaii recognize the fact that rind disease is of considerable importance, yet I doubt whether any of us quite realize how great the loss caused by it is; one gets so used to seeing a certain number of "rotten canes" in every field, that one comes to look upon their presence as normal. One does not fully realize that the loss is due to the attack of a parasitic fungus and that it is possible, by fighting the fungus and altering the conditions that favour its spread, to reduce the amount of damage.

To bring before you the actual extent of the loss that the rind disease is now causing in your cane fields, I take the following fact obtained by Dr. Cobb from actual counts in the field. In one case the cane left on the ground represented about one ton of sugar to the acre. That is to say, that if the cane left on the field had been sound cane that portion of it left on an acre would produce about a ton of sugar. The area counted over, in this particular case, was representative of 200 acres.

A few years ago, when the leaf hopper was at the height of its glory in reducing the vigour and vitality of your canes, these figures would have been much higher. I have been assured that, at that time, there were acres and acres of cane to be seen on which the majority of the sticks had been ruined by rind disease.

I am sure that if managers would make definite counts of the number of diseased canes present in their fields, they would

realize better the losses caused by fungus diseases and would be keener on preventive measures. Take a given area, which should be a representative one, not in the worst nor in the best fields, and after the cane has been reaped go through it and, using a counting machine, count the number of "rotten canes." It would then be easy to estimate the weight of these canes, supposing them to have been sound, and from this the loss of sugar per acre. Multiply this by the acreage reaped and I am pretty certain the results would surprise you. The figures would also be exceedingly valuable to the Division of Pathology and Physiology.

To illustrate the losses which may be brought about by rind disease, I cannot do better than mention the experience West Indian sugar planters had with it. In Barbados, for example, in 1895, the crop of the island, generally between 50,000 and 60,000 hhds., was reduced to 36,000 hhds. Speaking of the same year in Antigua, Dr. F. Watts says, "In 1895, the condition of the cane fields was pitiable. Rotten canes were to be seen everywhere; in some cases the condition of affairs was so bad that scarcely any sugar at all could be made. From the fact that the previous growing season had again been a very dry one, the impression still lingered that drought was largely responsible for the disaster. This idea was, however, exploded the following year, for although the growing season was a wet one, cane diseases were rampant, and the fields filled with rotten cane." The actual figures are also given by Dr. Watts—from 1881 to 1894 the average annual production was 13,113 tons; in 1895 the production was 6,685 tons. How much of this loss was due to disease cannot be definitely stated—Dr. Watts estimates it at from 2,000 to 3,000 tons.

Even more strikingly illustrative is the fact that since 1895, Barbados and the islands to the north have had to abandon the cultivation of the Bourbon cane (your Lahaina), owing to its susceptibility to rind disease. Imagine what it would be here, supposing the Lahaina to be practically the only variety grown, if every plantation on the islands were forced to give up the cultivation of that variety, and the only hope was to take up that of other, practically unknown, kinds. Yet that was the position of sugar planters in some of the West Indian islands, all through rind disease, and I consider that it is greatly to their credit, and to the credit of the Agricultural Department there, that the situation was faced so well and that the industry recovered so quickly.

It is to be hoped that Hawaii will never suffer from such an

epidemic of rind disease as the one I have just described. At any rate, if such a one does occur we shall have a number of well tested varieties to replace any that may have to be abandoned.

Symptoms.

The later stages of rind disease are very characteristic and are doubtless familiar to everybody. The earlier symptoms, however, are not so well marked and can quite easily be overlooked, so that a good deal of the loss due to rind disease may not be noticed or, if noticed, may not be referred to the proper cause.

If one is on the look out for it, usually the first symptom is seen in the leaves, these being the most prominent organs and they also are always the first to suffer from any derangement of the plant's nutrition. The outer leaves begin first to dry up prematurely and turn yellow at the tips, and the drying spreads until the whole leaf is dead. Leaf after leaf may follow, in this way, until the whole tip of the stick is dry and dead. If this takes place while the plant is still young, and if the fungus is mainly in the upper part of the stick, the top may fall off and a bud lower down may attempt to carry on the growth. The attempt, however, is rarely a success—the fungus is too well established in the cane.

By the time the dying of the leaves has become a noticeable feature, we can usually find other evidence of the disease. Examining carefully the outside of the stalk, one sees on one or two of the joints dark discoloured patches, evidently abnormal. These show where the fungus is working.

Splitting open such a cane, we find that the tissue under the blotches is all discoloured and evidently diseased. The normally whitish ground tissue is bright or dark red or reddish brown. Whenever it is possible to trace the discoloration to its starting point, this will always be found to be a wound of some sort. The wound may be a borer hole, a leaf-hopper puncture or a wound made in stripping, the borer wounds being perhaps the most favourable to the fungus, especially in the older parts of the stalk.

In the next stage the discoloured areas become somewhat sunken, lose their colour and become a dirty dull yellow. The tissues underneath have been drained of their contents and killed by the fungus, hence the shrunken appearance of the stem.

If the disease proceeds further, we find the whole cane discoloured and brown, it is very light in weight, the internodes are shrunken, and we see a number of small, black, kinky, hair-

like bodies projecting from the stem. These will be seen to have been formed below the rind, which they have burst through in getting to the outer air.

These kinky threads are really masses of spores of the fungus, *Melanconium* (*Trichosphaeria*) *sacchari,* which causes what we call rind disease of the cane. Each thread consists of a mass of thousands of spores, bound together by a mucilaginous sub-

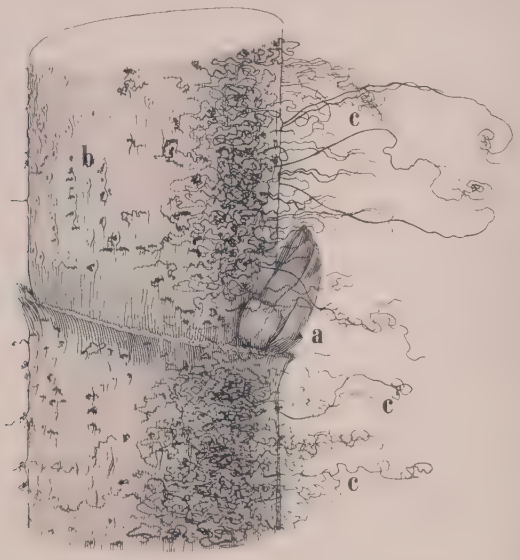


FIG. 6. Small portion of a stick of cane attacked by the fungus causing rind disease. *a*, one of the buds of this stick of cane; *b*, the pustules from which the spores produced by the fungus issue to the outer air; *c*, the kinky, jet black, hair-like masses of spores issuing from pustules similar to those shown at *b*. It is not often that this feature of the disease may be seen in cane fields, but the specimen here shown may be easily duplicated in the office. It is only necessary to take a stick of cane still somewhat juicy, but showing the characteristic pustules of the disease, and place this stick of cane in a drawer or cupboard where it will not dry up too rapidly and where there are no draughts, to have it show, in the course of a few weeks, precisely the features shown in the illustration. If a portion of one of these hairs be examined under a microscope, it will be seen to be composed entirely of spores of the rind disease fungus, as seen in Fig. 7. It must be noted, however, that the appearance of pustules and black hairs, on a stick kept for some time, does not prove that the stick was affected before being cut. The spores of the rind fungus are very numerous in the neighborhood of cane, and a stick will soon be infected from spores carried in the air.

stance, which if allowed to dry, becomes quite firm and holds the spores together so well that it is difficult to separate them, even in water. The spores, of course, are extremely minute, though

large compared with some we have to deal with—it would take over 800 of them placed end to end to reach half an inch. They are dark brown in colour, elliptical, and one-celled. Similar pustules are formed on the leaves and leaf sheaths.

To obtain these spore pustules from a stick of cane which has been cut and allowed to stand about some weeks, is no sure proof that that cane was, when cut, suffering from rind disease. You can take the healthiest and cleanest stick of cane, put it by in a room for a few weeks, and it is sure to develop the pustules. One explanation is that the spores of the disease are so abundant, especially in the neighborhood of cane fields, that one is sure soon to fall on a cut end, and there start growth and destroy the cane.

For this reason all estimates of the percentages of "rotten cane" must be made immediately after the cane has been cut.

FIG, 7. A few of the spores of *Melanconium sacchari* taken from one of the black, kinky hairs as shown in Fig. 6. On the right are shown two crystals of calcium oxalate, these often accompany the spores. The Melanconium spores are produced at the pustules, one of which is shown in section in Fig. 10, in immense numbers and burst through the rind of the cane.

The individual spores are pale brown in colour (in the mass black), they are one-celled, cylindrical, rounded at the ends, and straight. Usually each spore has two well-marked vacuoles, symmetrically arranged, one near each end.

LIFE HISTORY OF RIND FUNGUS.

The spores are the chief means by which the rind fungus spreads itself and they form a convenient starting point for a study of the life history of the fungus.

If we sow a fresh spore in a drop of water, it begins in a few hours to start to germinate. A thin white tube or hypha is put out near one end, this hypha continues to grow, cross walls are formed dividing the protoplasm into separate compartments, and one or two branches may be produced. This growth takes place, of course, at the expense of the food

FIG. 8. *Melanconium* spore germinating in water. A thin colorless tube is put out near one end of the spore, which grows at the expense of the food material stored away in the spore.

FIG. 9. More advanced stages of the germination of *Melanconium* spores, also in water. Quite long, branched hyphae have been produced almost entirely at the expense of the food stored in the spore, together with the small amount of salts dissolved in the water. Growth will not proceed much further than this, unless some organic food (sugar) is added to the medium in which the fungus is growing.

material stored in the spore. When this is consumed, the hypha dies. This may also take place in the field, the spores germinating before they are brought to a suitable source of food and so die off.

If, on the other hand, we sow these spores in a drop of water containing suitable food material, for instance, in a decoction of cane, or sow them on a sterilized slab of cane, the fungus will be able to develop much further. The growth starts as before, a colourless hypha is put out from either one or both ends of the spore, it grows, taking its food from the cane extract, branches, septa are formed, the whole process going on very rapidly. Within 48 hours a very considerable mycelium will be formed, under favourable conditions, started from a single microscopic spore. Soon the mycelium starts in again to form spores. Thus this fungus, like most of those causing important cane diseases, is able not only to exist, but also to grow and reproduce itself—carry through its whole life history—using for its nourishment dead material. This fact is of practical importance, as it shows the importance of making a clean sweep of cane fields after each crop and not leaving dead canes about to serve as nurseries for the fungus.

Infection of the Cane.

We have seen how the spores of the rind fungus grow when sown on artificial media and how, in a few days, the mycelium produced from a single spore, will be producing spores by the thousand. The next questions to attack are: How can these spores give rise to the fungus within the cane plant and what happens when the fungus starts growth there?

To answer these questions we must proceed in true scientific style, to experiment. We want first of all to select canes that are free from the rind fungus to start with. Secondly, these canes must be susceptible to rind disease. As I shall show, later, these conditions are very seldom combined in sugar-growing regions.

Supposing we have such a cane, take some spores from our artificial cultures (for this is the only way to be certain we are dealing with one, and only one, fungus), and sow them in a drop of water on the outside of the epidermis. We must shade the drop, so that the spores when they start to germinate will not dry up prematurely. The result is just the same as when the spores were sown in a drop of water on a glass slide. The germ tube starts, grows a little way and then dies from lack of nourish-

ment. The rind fungus, then, is not able to penetrate the uninjured epidermis, even of a susceptible cane.

If now we make a small wound in the cane by sticking the point of a sterilized needle through the epidermis, then insert some spores, also with a sterilized needle, into the wound, a different result follows. The fungus no longer has to attempt to penetrate the tough cuticle, but only the thin walls of the sugar-containing cells. This it is able to do; the infected spot becomes diseased; sooner or later the external symptoms appear, winding up with the production of the spore pustules.

Again, if we introduce the spores into a wound, such as one made by premature stripping, or by boring insects, the same results follow, the cane is infected and shows the rind disease.

These and similar experiments show us what we started in to find out. The spores of *Melanconium*, found on rotten cane, can give rise to rind disease. The mycelium produced from these spores cannot penetrate the healthy epidermis, but it can, under certain conditions, when introduced into a wound, enter the living thin-walled cells, and bring about the death of the cane.

Natural Infection.

Under field conditions, of course, the spores gain access to the interior of the plant through natural wounds. Perhaps the most abundant wounds offered for this purpose are leaf-hopper punctures; even more favorable for the fungus are the tunnels of borers, leading as they do right into the heart of the sugar-containing tissue; other wounds may be made in stripping; in fact, it is a difficult matter to find a stalk of cane without a wound of some sort. The spores are produced in immense numbers on every stick of rotten cane. They are doubtless distributed partly by the wind, though the mucilaginous substance by which they are joined does not favor this; insects are certainly also important distributers of the spores, leaf-hoppers will get infected and deposit the spores in their punctures, ants will carry them into borer and other wounds in their search for food, flies may also serve the fungus in the same way.

Of course the chances of any particular spore reaching a favorable spot for growth are very minute; but when you multiply them by the immense numbers of spores which are present in every cane field, things become much more even. Another point to remember in this connection is that the spores do not retain their vitality indefinitely; dessication, or, even better, alternate wetting and drying, will kill them in one or two months, perhaps weeks. But against all this the fungus is able to fight by means

of its abundant *and continuous* production of spores from every stick of infected cane.

Growth of Fungus in Sugar-Cane.

When the fungus spore is brought into a wound in the stem of the cane, it finds there very favourable conditions for germination and growth. The juices from the wounded cells supply the fungus with sufficient moisture and just the right nourishment in the shape of sugar and mineral salts. In this way the fungus can maintain itself in the wounded tissues, as a saprophyte, for quite a long time.

Ultimately, however, the fungus will attempt to enter the living cells bordering on the wound. It has first of all to break through the thin cellulose cell-wall and then to overcome the resistance of the living protoplasm. The tip of a fungus hypha probably secretes a ferment which dissolves the wall and through the hole thus made the hypha grows into the cavity of the cell.

By means not yet fully understood, possibly by the secretion of poisons, the cell protoplasm is killed and the fungus now has the whole contents of the cell—dead protoplasm, cell sap with its contained sugar, etc.,—at its disposal. So it goes on from one cell to another, branching in all directions, until the whole of the tissue in the neighborhood of the point of infection is filled with the fungus mycelium.

It is in the cells that are thus attacked and destroyed that the plant stores its reserve of sugar, the sugar for which we cultivate the cane and the sugar which the fungus, like ourselves, has to steal, because it cannot make it for itself. Of the three, the fungus is now in the best position; it passes from cell to cell, consuming some and destroying some. Large masses of tissue are killed; the cells dry up and become discolored, thus giving rise to the sunken discolored areas we notice on the outside.

The fungus, moreover, does not stop with the destruction of the sugar-containing tissue. The hyphae are able to bore their way also through the hard woody walls of the vessels, which are carrying the water current. Here the fungus is able to obtain water and mineral salts in greater abundance than in the sugar parenchyma. The hyphae branch and interweave in the large vessels, and finally plug up, more or less completely, their cavities. The cane plant by this attack loses in two ways,—it loses the water and salts actually taken in by the fungus, while also the supply of raw food and water to the leaves is reduced by the mechanical obstruction offered by the interwoven hyphae.

If you look at the damage from the point of view of the agriculturist or plant physiologist and its effect on the nutrition of the cane, you will see that this damage is far more serious than the loss of the sugar tissue. The sugar is only a reserve, to be used when any extraordinary call is made for food, for example, when tassels are formed or, when a piece of cane is used as a cutting, for the production of shoots and roots.

An interference with the water current, on the other hand, interferes at once with the actual nutrition of the plant. The result is starvation, stoppage of growth, death of the leaves and no formation of reserve sugar. This result, is, of course, more or less complete, according as the interference with the water current is greater or less.

To take an illustration from another kind of warfare,—the destruction of the sugar reserves would be equivalent to the destruction of all the flour, meat, bread, etc., in an invested town by the besiegers: the destruction of the water supply would, similarly, correspond to a seizure of the water reservoirs, the live animals and the grain supply; the latter would, of course, be a far more serious blow to the defending forces.

In this way the later symptoms of rind disease are brought about. The leaves begin to suffer from the lack of a proper supply of water and food salts, and commence to dry up prematurely. Their activity, in the production of food stuffs is reduced; consequently the nutrition of the plant suffers. Meanwhile the fungus is extending its ravages from one internode to another, killing the sugar cells and consuming their contents, attacking one vascular strand after another, until every vessel contains the mycelium. Finally, if the nutrition of the plant is sufficiently affected, the stick or the upper portion of it dies, becoming dried, shrivelled and worthless; partly as a direct result of the fungus attack, partly as an indirect one. With root disease, the damage, you will remember, is to a far greater extent the indirect result of the fungus attack and the loss is not so complete.

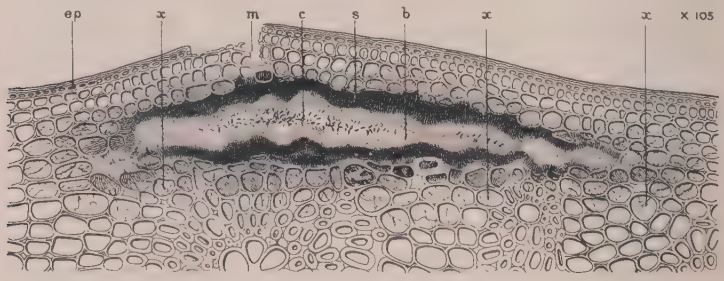
If the nutrition of the cane is not so far weakened, the stick may go on living and producing enough sugar to supply the needs of the fungus. Very little is stored by the plant itself, so that the result, especially from the planter's point of view, is practically the same.

Reproduction of the Fungus.

The final stage of the disease, at which also we began our study, is the production of the reproductive bodies of the fungus,

the *Melanconium* spores. The fungus hyphae just within the rind commence to grow and branch extensively, splitting up the cane tissue as they do so. Finally, by continued branching and interweaving of these hyphae, a thick cushiony mass is produced, lying

FIG. 10. Section through the outer part of a cane stem, passing through one of the pustules of *Melanconium*. ep, strongly cuticularized cells of the epidermis of the cane stem; x x x, hyphae of *Melanconium* filling the thick-walled cells of the outer ground tissue; m, rupture in the epidermis and outer tissues of the cane stem, brought about by the growth of the spore-cushion of the fungus and the production of the spores; it is through the split thus formed that the black, kinky tendrils of spores are extruded;



c, spores of *Melanconium*, a few of these are shown, more highly magnified, in Fig. 7; s, stroma or spore-cushion of *Melanconium*, the stroma is quite irregular and forms a layer, for the most part, lining the cavity its growth has produced between the cells of the cane rind; the hyphae composing it are dark-colored and very closely woven together; b, fertile hyhae or conidiophores, these stand up perpendicular to the surface of the stroma, they are delicate, white hyphae and from their ends the spores, c, are abstricted.

a few layers of cells within the epidermis of the stem. This mass accumulates large quantities of food stuffs, drawing on the mycelium back in the tissues of the cane. The cushion does not necessarily remain flat, but appears to be usually convoluted; it thus has the appearance in sections, sometimes, of being a closed chamber.

Soon after its formation the cushion begins to take on a dark color, finally becoming almost black; the color, together with the closeness with which the hyphae are interwoven, makes it very difficult to make out the structure of a ripe spore-cushion.

From the cushion there arise very numerous, delicate white hyphae. These stand up perpendicular to the surface of the cushion, like the pile on velvet. These are the spore-bearing hyphae—the conidiophores. The tip of one of these hyphae begins to swell and become filled with dense protoplasm. It becomes considerably wider than its parent hypha, from which it accumulates a store of reserve food. A cross wall is formed cutting off this tip, it thickens its walls, becomes rounded at the corners; the wall darkens in color and the elliptical dark brown

body is cut off as a spore. This process is taking place all over the spore-layer and in this way the thousands of spores emitted from each single pustule are formed.

The pressure caused by the growth of the spore layer and the spores is sufficient to burst the rind of the cane, so that a small crack appears. Through the opening thus made, the spores are forced by the continuous formation of others behind them, and, being held together by a sticky substance, appear as the familiar kinky threads.

RED ROT OF THE SUGAR-CANE.

I want now to leave the rind fungus—*Melanconium*—and its effects and say a few words about another fungus attacking the stem of the sugar-cane. The fungus is *Colletotrichum falcatum*, and the disease it causes has been called the "red rot" of the cane. I have been working on this fungus recently and hope shortly to publish a bulletin dealing with it.

I have two reasons for introducing this subject now: the first is that I want some information from you as to the extent to which cane suffers from the "red rot" in these islands; the second is that the red rot fungus has been considerably mixed up, in literature, with rind disease, so that in order to have clear ideas on various debated matters it is necessary to know something of the *Colletotrichum* and its effects.

It is necessary to be quite clear about these two fungi themselves, apart from the diseases they bring about. There is first the "rind fungus"—*Melanconium sacchari,* I have described to you, which produces the black pustules in the rind of the cane and the spores of which come out together as black kinky threads, the spores being dark in color, elliptical, and straight. On the other hand, there is the "red rot fungus," *Colletotrichum falcatum*, which I am now about to describe to you and which is as distinct from the other as, say, sugar-cane is from Bermuda grass.

It may seem superfluous to insist on this point, but you will see that things get a bit more mixed later on.

The red rot is a disease that has practically no external symptoms; it is only when the cane is badly diseased, that there is a premature yellowing and drying of the leaves with a stunting of growth. This is doubtless the reason why we hear so little of the disease in Hawaii.

However, on cutting open the stem of an attacked cane longitudinally, the disease is shown very clearly. The diseased parts

are red and have a distinct acid smell; the red color is not evenly spread through the tissues, but appears in blotches, here darker, there lighter. Besides this there are white spots in the diseased area, not the creamy white of healthy cane tissue, but dead white. These white spots in the middle of the blotchy red, diseased areas are a sure sign of the "red rot."

Compared to the rind fungus (*Melanconium*), *Colletotrichum* very rarely produces spores; I found them on dead leaf-sheaths, and Dr. Perkins tells me he has found them on dead leaves, but I have never found them in specimens sent in for examination. Even so acute and trained an observer as Dr. Cobb did not record them on his tour of Hawaii.

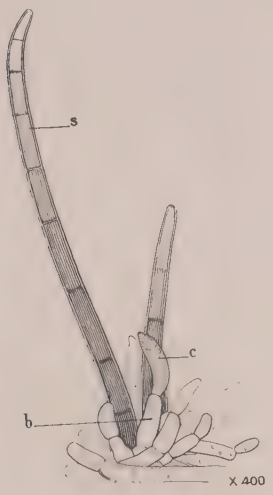


FIG. 11. Stroma of *Colletotrichum falcatum*, the fungus causing Red Rot of the sugar-cane. This stroma was removed from a leaf-sheath, mounted in water, and drawn with the camera lucida. *s*, seta, this is a stout, brown bristle, easily seen with a hand lens; in *C. falcatum* the setae are sterile, but in at least one other species of the genus, *C. gossypii*, they bear spores, exactly like those borne on the short conidiophores; *b*, fertile conidiophore, a short colourless hypha arising from the stroma; *c*, conidium or spore, produced at the end of the short conidiophore; mature spores are shown, more highly magnified, in Fig. 12.

The spores are produced in much the same way as in *Melanconium*: a small spore cushion is formed, from which grow out the delicate white hyphae that bear the spores. Besides these hyphae there grow out some much stouter, darker and longer hyphae, which stands up stiff like bristles; these "setae" are large enough to be seen with a good hand lens. The spores are one-celled, colourless and curved.

These spores, if sown in water, germinate, giving rise to hyphae with a few short branches. Sown

FIG. 12. Spores, conidia, of *Colletotrichum falcatum* taken from a pure culture of the fungus. They show the variation in size and shape usually met with. These spores are colourless, one-celled, usually slightly curved, and with one large vacuole near the centre; the spores are filled with large refractive granules.

in a nutrient medium, containing sugar, they give rise to a considerable mycelium, which in a few days commences to form spore

cushions; on this arise the short fertile hyphae and the long sterile setae. Besides these spores, the fungus also produces thick-walled, brown bodies (*chlamydospores*) at the ends of ordinary vegetative hyphae. These are undoubtedly resting bodies, which enable the fungus to rest over for a time when conditions are unfavorable for its growth. They are sometimes produced in large numbers, both in cultures and in infected cane which is drying up.

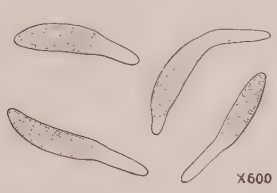


FIG. 13. Early stages of the germination of the spores of *Colletotrichum*, from a "hanging drop" culture. This stage is seen about three hours after the spores are sown. Germination usually takes place first at one end of the spore, later a germ tube usually arises from the other end also.

To infect cane the spores must be brought into a wound and preferably a wound that goes through the rind to the sugar-containing tissues. Here the spores gives rise to a mycelium which attacks the living cane cells, giving rise to the disease known as "red rot," the symptoms of which I have already

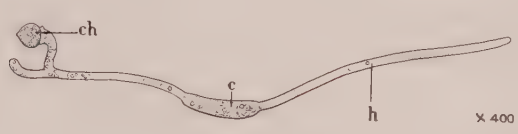


FIG. 14. Later stage in the germination of a spore of *Colletotrichum*. *c*, spore which has germinated at both ends; *ch*, chlamydospore, a thick-walled, brown resting body, in this case produced at the end of a short branch arising direct from the germ tube; these chlamydospores are found in the tissues of diseased cane; *h*, hypha arising from one end of the conidium.

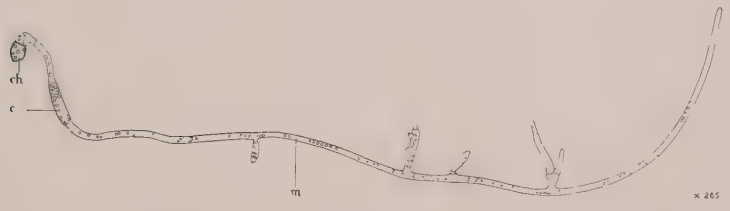


FIG. 15. Further stage in the germination of a conidium of *Colletotrichum* in water. *c*, original conidium (spore); *ch*, chlamydospore, arising at the end of a short hypha proceeding immediately from the conidium; *m*, small mycelium, branched and septate, which has arisen from the germ tube proceeding from the other end of the conidium. No conidia were formed on the mycelium growing in water alone.

described. With Yellow Caledonia cane, at least, the progress of the disease is slow; six weeks after I had inoculated some

canes with spores from a pure culture, only one internode had been attacked, although there were indications that the disease was beginning to extend to the internode above. The fungus attacks mainly the sugar-bearing cells in the centre of the stalk; except in the last stages of the disease the vascular bundles are not attacked, so that the general nourishment of the cane does not suffer. The sugar is partly consumed but a great deal more is inverted; in this way, perhaps, the first sign of an epidemic of the disease will be a falling off in the yield of sugar from apparently normal though rather stunted cane. Also, slighter attacks might remain unnoticed, in spite of the fact that a considerable total amount of sugar was being lost.

UNIVERSAL PRESENCE OF RIND FUNGUS.

Earlier in the lecture, I drew attention to the fact that sooner or later any cut stick of cane, if kept under observation, will develop pustules of the rind fungus. This fact is capable of more than one explanation. It may be that rind fungus spores are so abundant that the cane soon becomes infected after it is cut, or that spores are present on the cane when it is cut which afterwards develop. Another explanation would be that every cane contains inside it the mycelium of the rind fungus; in other words, that practically all our canes are attacked by a very mild form of rind disease. Of the three explanations one of the two first would seem to be the most reasonable, though there is no improbability about the third.

As you will readily understand, this is not an easy question to settle, but I thought it important enough to warrant one or two experiments. I therefore took six clean healthy sticks of cane, two of which I left exactly as they were brought in; from two others I cut off the ends with a sterile knife, then washed them pretty thoroughly in 2% formalin, this being to destroy any rind fungus spores that might be on the outside; the third pair, I treated like the second, namely, disinfected them externally, but I left these in our germ free culture chamber, where there would be little chance of external infection.

The difficulty lies in disinfecting the cane externally, sufficiently effectively, without a prolonged soaking which might kill the cane tissues and at the same time any fungus mycelium that might be there. There are many dead bud scales, bases of leaves, etc., which might shelter fungus spores from any but a prolonged disinfection.

If then the disinfected sticks kept in the germ-free air do not

show pustules, it will be pretty certain that they did not contain any rind fungus mycelium. If neither pair of disinfected canes show the pustules, then it would seem that infection was by means of spores on the surface when they were cut. The opposite results will not prove the contrary, owing to the difficulties of proper disinfection.

In another experiment I took two pieces of cane, cut out two short pieces a good way from the ends, using a sterilized knife, and dropped them immediately into a jar of 2% formalin. They were kept there 10 minutes, taken out and allowed to dry partially, then placed in two tall glass cylinders with cotton-wool stoppers which had previously been sterilized. In a few days, there developed, from every bud scale and bit of leaf-sheath at the nodes, a luxuriant growth of the common green mould. The experiment just showed how difficult it is thoroughly to sterilize the outside of the cane. I put the canes back into formalin for half an hour, sterilized the cylinders again and replaced the canes. Ten days later, *Melanconium* pustules began to appear on both pieces of cane, but so did also green, white and red moulds. The result of this experiment is, therefore, merely to emphasize the difficulties of the attempt and the impossibility of drawing conclusions from the appearance of pustules.

In the other experiment both of each lot of canes have developed the pustules. The result is, therefore, inconclusive. The fact, however, that in four cases it took six weeks for the pustules to appear and in one case (in the germ-free room) ten weeks and that then they appeared near one of the cut ends would indicate that infection took place subsequent to the removal of the sticks from the field.

DIFFERENT VIEWS WITH REGARD TO THE CAUSE OF RIND DISEASE.

Different investigators have come to very different conclusions as to the real nature of rind disease and the parasitism of the rind fungus—*Melanconium*. On the one hand, there is the view that *Melanconium* is a true wound parasite, which when introduced into a wound, gives rise to rind disease in the manner I have described.

The second view is that *Melanconium* has nothing to do with rind disease, but that the true cause of rind disease is the red rot fungus—*Colletotrichum*. According to this view the *Melanconium* only can attack cane which is dying from the effects

of the other fungus injury; it is therefore relatively unimportant. This view is based on certain experiments, which showed that *with the canes experimented on, Melanconium* was not able to bring about the disease when introduced into a wound in a healthy cane; if, however, spores were introduced into a cane which had previously been inoculated with *Colletotrichum* then the disease appeared. You will understand now why, when I started on a study of rind disease, my first step was to investigate *Colletotrichum falcatum,* particularly when I had the chance of obtaining spores with which to begin.

My own view, which has at least the merit of being based on over four years' experience as a sugar-cane pathologist, differs from both those I have endeavored to present to you. It is that rind disease is quite distinct from the red rot caused by *Colletotrichum falcatum.* The symptoms of the two diseases are not the same, it being possible to recognize the rind disease from external symptoms in its early stages, while I have never seen described any earlier external symptom of the red rot than the dwarfing of the plant and dying of the leaves. Also the fungi do not necessarily accompany one another. Canes I have infected (and successfully) with *Colletotrichum,* after three months, show no sign of rind disease or *Melanconium* pustules. The fact that I have never found *Colletotrichum* spores on cane attacked by rind disease may be due to the rarity of the fruiting form of this fungus; I should have expected, however, if the fungus were always present, that I should have occasionally found the spores, especially as I was always on the look-out for them.

On the other hand, and speaking with regard to the varieties at present in cultivation here and in the West Indies, I do not consider *Melanconium* as a markedly parasitic fungus. That is to say, that a healthy cane of our varieties would resist the attack of *Melanconium,* even if the fungus gained entrance to the interior tissues by a wound.

If, however, the vitality of the cane is in any way lowered beyond a certain point, then the cane loses its resistance and becomes liable to the attack of the rind fungus. The lowering of the vitality may be the result of several causes. In these islands the most common cause is probably the leaf-hopper; another is poor nutrition of particular canes, either by the growth of more vigorous canes robbing them of their soil food, or by similar canes overshading them; another cause, probably, is the attack of other parasitic fungi among them doubtless *Colletotrichum falcatum.* Rind disease often appears to finish up canes that have been attacked by the bacterial disease known as "Top-

Rot." The large losses from rind disease here, when the leaf-hopper epidemic was at its height, were, no doubt, partly due to the numerous punctures affording entrance to the fungus; but even more important, from my point of view, was the loss of vigor in the canes caused by the repeated attacks of the insects, thus rendering the canes susceptible to infection.

This view has nothing startling about it; similar cases are well known in both animal and plant pathology. We all, when healthy and in good condition, are able to throw off attacks of disease that might be fatal were our vitality decreased. In an epidemic it is the ill-fed, ill-clad and ill-housed class that usually suffers most severely, while the well-fed and well-housed class remains comparatively immune. For nearly every plant disease, varieties of the attacked plant vary in their immunity to the disease; those with more than the average immunity, we call resistant varieties; those with less, we call susceptible. It is all a question of degree and the point is that with regard to rind disease, we might call all our present varieties resistant. But resistance is never absolute, there is always a certain percentage of individuals, whose resistance is for one reason or another less than the normal for the variety and these will be attacked by the disease provided infection occurs.

RELATION BETWEEN *MELANCONIUM* AND *THIELAVIOPSIS*.

I debated a long time before I decided on bringing the next question before you at this meeting. It is still in a very unsettled state and I had intended (and still intend) to make it the subject of investigation after I had completed my work on the *Colletotrichum*. It is, however, so important a point that I finally decided on laying the theory and the facts for and against it before you.

The question is briefly this. Is the pine-apple disease fungus (*Thielaviopsis ethaceticus*) merely a stage of the rind fungus (*Melanconium sacchari*)?

The question is by no means a new one. It was raised when first the life history of the *Melanconium* was worked out; subsequent workers, however, do not appear to have realized the importance of it, being too busily engaged in working out the question as to how far *Melanconium* or *Colletotrichum* was responsible for rind disease. Whatever views we accept as to the degree of parasitism of *Melanconium*, as the rind fungus, there can be no doubt of its importance and destructive ability as the pine-

apple disease fungus—that is, if the two are really one and the same.

The evidence for the view that *Thielaviopsis* and *Melanconium* are different stages of one and the same fungus is, briefly, that when we sow *Melanconium* spores under certain conditions in culture media, the mycelium which arises produces spores which are identical, in form and size and method of formation, with the spores of *Thielaviopsis*: other observers have found this and I have also secured the same results. On making a few hurried trials for the purposes of this lecture, I was unable to repeat my previous results.

Also, if the two fungi are really one, we ought to be able by sowing *Thielaviopsis* spores, under the right conditions, to get the *Melanconium* spores. This, no one has yet succeeded in doing,—probably it is all a question of getting the right conditions.

Just as some flowering plants reproduce by tubers, bulbs or bulbils as well as seeds, so a great number, I might say the majority, of fungi have more than one method of reproduction.

If the connexion be proved, it will explain some things about pine-apple disease that are at present rather obscure. For instance, how is it that pine-apple disease turns up whenever cuttings are planted and where conditions are favorable for it? If the fungus were exclusively a soil-inhabiting one and only attacked cuttings after they were sown, it would be difficult to see how it could spread to new lands except by the planting in it of diseased cuttings: considering the very marked nature of the disease and the rapidity of its course, this is hardly likely to be done. If, however, the fungus possesses so widely distributed and abundant aerial stage as the *Melanconium*, it is easy to understand how cuttings can be infected by *Melanconium* spores almost as soon as they are prepared: and this would account for the presence of pine-apple disease in any locality where *Melanconium* is present.

TREATMENT.

The preventive treatment for rind disease follows naturally from the study of the life history of the fungus and the interrelationship of it and the cane plant. All that remains for me to do now is to bring together what I have already indicated as to the lines treatment should follow.

It might be said, what is the use of our taking any measures against rind disease? We cannot hope to exterminate all the millions of spores on every acre of cane land; even if we leave one spore, it is quite capable of setting up the disease again and

all our efforts will be wasted. Besides, we are told that our canes resist the disease, that it is only the weakly canes that are attacked, so what is the good of trying to save only these?

The second objection itself, if looked at rightly, answers the first. Consider the chances against any single spore infecting a cane plant. Infection has to take place within a short time after the spore is formed, especially under field conditions. The spore has to be carried, quite by chance, to a suitable wound in a cane and if you like you can work out the total surface area of the wounds in a field of cane compared with the total surface on which that spore may be deposited. Then that wound has got to be in a susceptible cane. Altogether the chances are very minute, more so than you would at first think. Suppose we take them at ten million to one, and take for example a field in which there are a thousand million spores to the acre; in that case you would have 100 canes attacked per acre. Now, suppose you could reduce the spores 90 per cent, as could very certainly be done, your number of canes attacked per acre will be only 10. The figures will vary, but the principle remains the same and it will work out correctly if you apply it to a sufficiently large area.

You must remember, too, that the more disease-producing spores you destroy this year, the less there will be to do in this way next year; while if you let it alone, the trouble will increase up to a certain maximum, determined by the disease-resisting powers of your cane varieties.

Because our bodies can resist attacks of disease-producing organisms, are we justified on that account in exposing ourselves needlessly to infection—say, drinking water we knew to be swarming with typhoid germs or mixing freely with small-pox patients?

The point is whether it is worth while reducing losses from rind disease, which have been reliably estimated in some cases at a ton of sugar per acre, by 90 to 95%, by the use of the measures I am now about to outline.

Destruction of Infected Material.

Rind disease is spread by the spores of the rind fungus; the spores are produced on rotten canes. Obviously then, if we want to reduce the chances of infection, we must destroy the breeding grounds of the fungus. In this connexion I cannot do better than quote Dr. Cobb, who has carefully studied the question, in the field, on a number of plantations:

"The number of the spores of this disease that exists on every plantation is past calculation and almost inconceivable. This

abundance of the spores of the disease tends, of course, to increase the losses. If there were no spores there could be no rind disease. Anything that can be done to reduce the number of spores will tend to reduce the amount of the disease. Something can certainly be done in this direction. Stalks dead of the disease can be destroyed and there can be no doubt that, in some cases, expenditure in this direction will be well repaid. . . .

FIG. 16. Cane left on the ground after burning off. Nearly the whole of this cane has been finished by Rind Disease. It was first attacked by borers and other insects. The amount of cane shown in the figure represents about one ton of sugar per acre. The area bearing this loss was about 200 acres in extent.

How to destroy them is the question. The ordinary burning off destroys only a part of these rind disease stalks, leaving the rest untouched or only partially roasted, to go on producing their millions on millions of spores.

"It is the custom on all the Hawaiian plantations to leave on

the ground after harvest the sticks of cane that have been attacked by borers or are worthless for other reasons. The reason for this is easy to understand. Such material is unsuited to the highest efficiency of the mill as an extractor of cane juice. It is also of such a nature that it may interfere with the clarification, evaporation or crystallization.

"Notwithstanding this I think it would be advisable to consider whether this material, which is really a menace to the health of future crops, cannot in some way be run through the mill and burned. This is a practice adopted in some other parts of the world. On Saturday afternoons a special run of the mill is devoted to the milling of such refuse as I have mentioned, the bagasse being burned. The juice is allowed to run to waste, being first sterilized.

"In Hawaii it is usual to attempt to burn this diseased material, but from careful observation I am certain that this attempt often ends in failure, that is to say, the fungus that exists in the waste cane is only partially destroyed.

"It may be that it would, at least from the disease point of view, be better if the harvesting of the fields were more in the nature of a clean sweep. If the diseased sticks are not too numerous, they will not seriously interfere with the working of the mill. The advantage would be that whatever diseased material was thus dealt with would be dealt with in the very best manner, that is, it would be utterly destroyed."

To this, I will only add that if the *Melanconium* spores thus produced on the rotten canes in the fields, are capable of infecting cuttings with the pine-apple disease, the importance of a thorough removal of these canes from the field and of their subsequent destruction is greatly emphasized. The means, by which this can be done, must be left for the managers to settle, according to the conditions on the different plantations.

Prevention of Wounds.

Having secured a reduction in the quantity of infecting material, the next point is to reduce, as far as possible, the points of entry for the fungus. The most important wounds from this point of view are those caused by the leaf-hopper and by borers. The leaf-hopper, as I have explained, is of double importance, not only do its punctures afford points of entry to the rind fungus, but its attack is liable to reduce the vitality of our canes, so that they become susceptible to the fungus attack.

Borer wounds are, as points of entry, even more favorable to

the rind fungus than the punctures of the leaf-hopper. They lead right into the centre of the stem and doubtless the ants, which frequent them, help to carry the fungus spores.

The control of these insects may safely be left to the Entomological Division.

A third class of wound is also, to a large extent, preventable. I refer to the wounds produced by careless or premature stripping. The whole question as to whether stripping is advisable or not is a complicated one; the answer, doubtless, depending largely on local conditions. The point can only be settled by experiments carried out in each locality. There is no doubt, however, of the harm caused by stripping too far up the stem, which tears away the young epidermis and exposes the tender tissues beneath to dessication, thus forming cracks, at which the spores of the rind and other fungi can enter. Careful supervision should, therefore, be exercised over the strippers to see that they do not attempt to make too thorough a job of their work.

Selection of Cuttings.

It is not likely that any canes showing marked symptoms of rind disease would be used for cuttings. The earlier stages are, however, not so well marked and it would be possible with careless selection of cuttings to plant some that were infected; in this way the disease would be perpetuated, or more probably the cutting would fail to germinate or would germinate but feebly.

Disinfection of Cuttings.

The possibility of cuttings being inoculated with *Melanconium* spores and so contracting pine-apple disease renders even more necessary than ever the disinfection of all cuttings before planting. The details of disinfection with Bordeaux Mixtures have already been treated of very fully by this Division, so that I need not go into that part of the subject now.

As an additional precaution, care should be taken that the cane to be used for cuttings is not brought near rind disease material before treatment, as the Bordeaux treatment is purely a surface one. Also, it is evident that no time should be lost after the cuttings are made before they are dipped. We have to guard against aerial as well as soil infection.

Cultivation.

There are always a certain number of canes which fail to get a proper start in growth and are overshadowed or in other ways

robbed of their proper share of food by their stronger neighbors. It is these starved canes which are most susceptible to rind disease. Whatever we can do by cultural treatment—cultivation, fertilization, irrigation, etc.—to reduce the number of weakly canes, will therefore decrease the amount of rind disease. Here, again, I can make no specific recommendations, as the cultivation cane requires varies according to the locality. Whatever cultivation, irrigation and fertilization gives the best and strongest cane, will also tend to reduce the amount of rind disease.

Resistant Varieties.

Our present varieties are certainly resistant to rind disease. Where, however, such losses as a ton of sugar to the acre, on an area of 200 acres, are possible, it is evident there is still room for improvement.

It is of great importance that the degree of resistance to rind disease should be noted in all variety tests, especially on plantations. At harvest it is quite an easy matter to calculate the percentage of rotten canes, and this will give you a very good idea of the relative resistance of the varieties. No variety showing a constantly high percentage of rotten canes should be recommended for plantation cultivation.

To illustrate the variations in this respect even among selected varieties, I will take some figures given in a report on variety tests in 1904 at Barbados. The first table I turned to gave the mean results obtained on thirteen plantations, with fourteen selected varieties. Taking the per cent by number of rotten canes, we find four varieties with less than 1 per cent., three with between 1 and 2 per cent., one with between 2 and 3 per cent., one with between 3 and 4 per cent., three with between 4 and 5 per cent., one with over 7 per cent., and one with over 11 per cent.

Other experiments would doubtless give slightly different figures, but only those varieties which show a constant high resistance should be finally selected. An indication of the resistance of a variety can be gained from small plot experiments, but the only reliable test comes when a variety is tested in the fields of a plantation, alongside one of the standard varieties. The essential point is that the two varieties should be grown under exactly the same conditions, as regards soil, cultivation, chance of infection, etc. When this is the case, the definite counts made at harvest of the percentages of rotten canes, will have a definite comparative value, otherwise they will be useless.

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